Development of Surface Display

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1   Introduction

Touch or force sensation is believed to be indispensable in the dexterous manipulation of objects in virtual environments. In order to simulate this kind of sensation, it is necessary to carry out an investigation on the contribution of force in manipulation tasks. However, before beginning such an investigation, a prototype virtual surface simulation system must be developed. In this paper, an outline of such a system, called Surface Display, is introduced.

First, the concept of Surface Display is stated and compared with the conventional concept of force feedback. Next, implementation of the concept is discussed, development of the mechanism and control system is stated, and the modeling calculation of a virtual object is described. In addition, as a methodology to improve the ability to approximate reality in force feedback, the idea of texture mapping in the tactile sense is presented. Finally, a brief summary of the discussion is given.

2   Concept

There has been considerable previous research on force feedback.[1][2] Most of this research is presented from the view point of simulating force that is transferred from the virtual object (Fig.-1(a)). This may be called the concept of 'force feedback'. In this concept, force is considered to be an output from the virtual object to the user. However, it is possible to adopt a different approach where, instead of force from the virtual object, the existence (or surface) of the object is simulated (Fig.-1(b)). This may be called the concept of 'surface displaying', where the word 'display' is used in the same sense as in "Force Display" described in a publication by Margaret Minsky.[3] In this concept, force is thought to be an input to the virtual object which affects its behavior, and the reactional force to the user is defined only as a implicit result of the object's behavior.

3   Mechanism

Existence of an object is perceived from physical contact with the object. As a virtual object does not have a real body, some real object must be prepared and presented to the user. In a
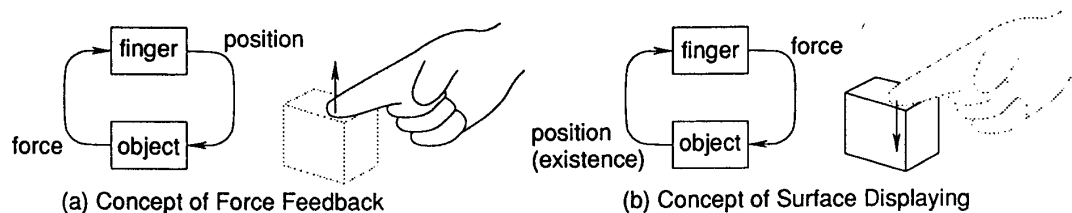

(a) Concept of Force Feedback   (b) Concept of Surface Displaying

Fig.-1 Concepts of Force Display

(a) Simplified Structure of Surface Display   (b) Simulation of Complicated Surface
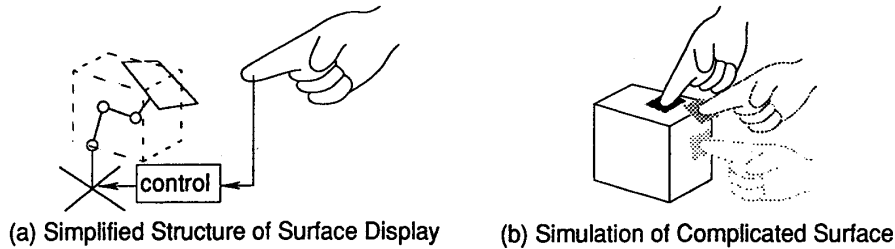
Fig.-2 Ideas in Surface Display

typical virtual environment, objects of various shapes at various positions must be displayed. However, it is difficult to prepare real objects with many different shapes. If it is assumed that only a small part of the user's body makes contact with the virtual object, then only the neighborhood of the contact point must be simulated. Moreover, if the contact area is very small, it is possible to approximate the area as a plane or some other similar surface.

It is also difficult but indispensable to know the point on the surface of the user's body where a virtual object is making contact, because the position and orientation of the displayed surface should change according to the motion of the user (Fig.-2). In the development of Surface Display, the area of feedback for tactile or force sensation was limited to a finger tip, and the shape of the finger tip was assumed to be spherical. This assumption makes the tracking of user motion and calculation of the contact point significantly easier.

Measurement of the absolute position and directional orientation of a finger in a wide work space is not easy. Furthermore, from the view point of simulating reality, measurement without physical contact is desired. One solution is to make use of a tracking mechanism incorporating a sensor which detects position and directional orientation in a small range covered by a magnetic field.

Two prototype mechanisms were developed in accordance with the discussion above.[4][5]

3.1   Prototype I

The first prototype mechanism has three degrees of freedom, which are used for both tracking the user's finger in 3D space and displaying the surface for tactile sensation (Fig.-3). In the tracking mode when the finger is not touching any virtual object, the finger is kept at the center of the contact tube on the force feedback head. However, when the finger is about to touch a virtual object, the display mode is selected in which the head stops moving towards the virtual object, and the finger moves off the center of the tube making contact with inner surface of the tube.
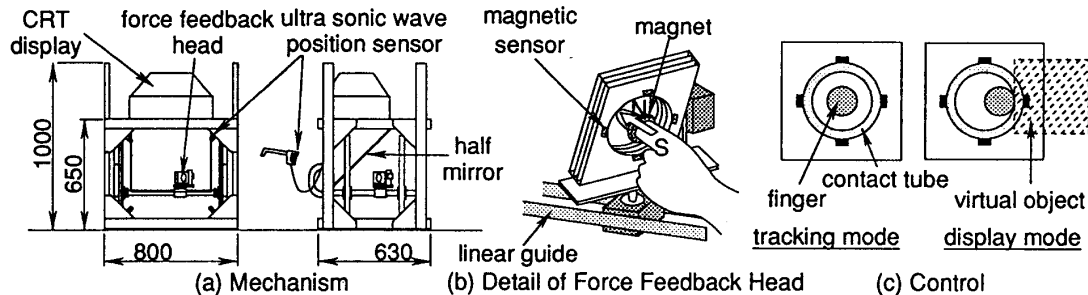

(a) Mechanism   (b) Detail of Force Feedback Head   (c) Control

Fig.-3 Mechanism and Control of Prototype I

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(a) Mechanism for Tracking Finger   (b) Mechanism for Surface Displaying
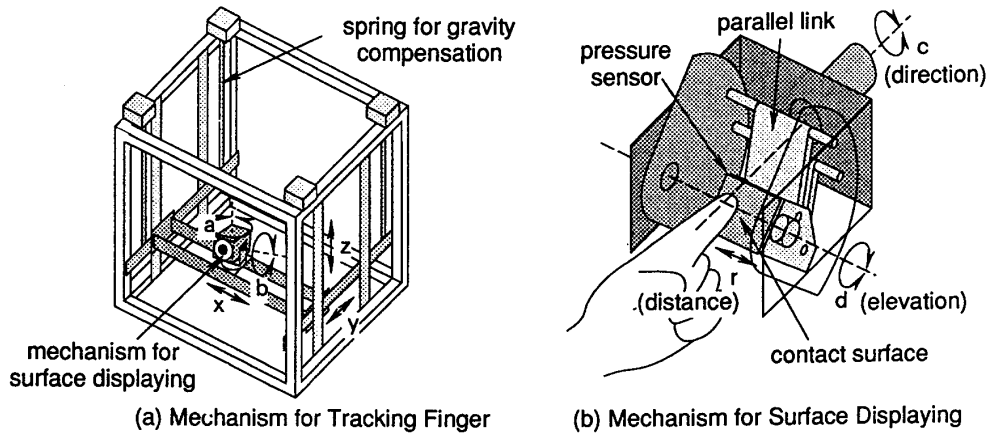
Fig.-4 Mechanism of Prototype II

3.2 Prototype II

The tracking mechanism for this prototype has five degrees of freedom, three for translation and two for rotation (Fig.-4(a)). The mechanism for displaying the surface has three degrees of freedom using a spherical coordinate system with direction, elevation, and distance (Fig.-4(b)). The position and angle of each degree of freedom is measured by a rotary encoder. A pressure sensor is attached to the contact surface and measures the force from the user's finger. This information enables the compensation for the servo error, ie. error caused by excess displacement of the contact surface when force is applied by the finger. It is also used in the calculation of model updating to simulate the behavior of the virtual object when it is manipulated. DC motors are used as actuators. All of the calculations for control are made in a digital signal processor (DSP) (Fig.-5).

4 Control

In this section, the control system of prototype II is discussed. In a 'force feedback' system, it is natural to apply a force servo or an open loop force control as a control system. On the other hand, in a 'surface displaying' system, in which the tangent surface of a virtual object must be simulated, it is more natural to apply a position servo as the control system.

Fig.-5 Control System

Fig.-6 Control of Prototype II

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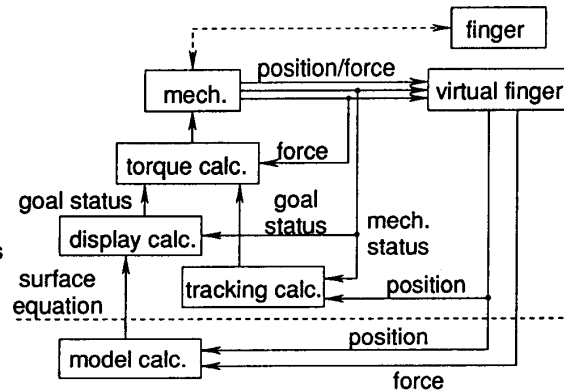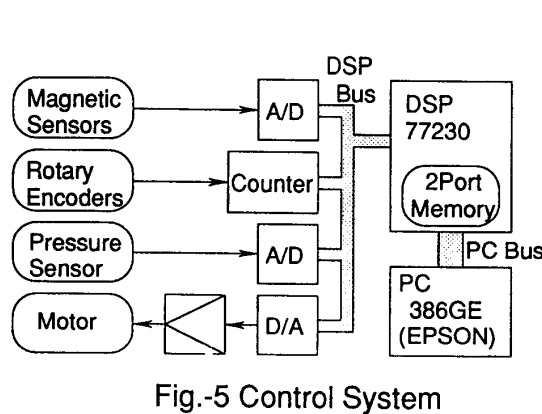
The position servo must update the position of the force feedback head according to the displacement of the user's finger to a new position and orientation as detected by the magnetic sensor, ie. the goal status of the tracking mechanism (Fig.-6). As the display mechanism is linked serially to the tracking mechanism, the goal status of the display mechanism is calculated from both the current status of the tracking mechanism and the equation of the surface to be displayed. The goal acceleration is defined in the same manner as PD control. From the goal acceleration and current status of the mechanism, actuation torque for each of the degrees of freedom is calculated by using the Newton-Euler method.

The maximum force that can be displayed by this mechanism was determined by the yielding force of the motor associated with the distance degree of freedom, and it was found to be about 300 gw (Fig.-7).

5 Model

In order to construct the tactile display of a virtual object by using these prototype mechanisms, in addition to the control of the mechanism, handling of the virtual object model is also needed. In this paper, this handling is called model calculation. Model calculation consists of two parts (Fig.-8). One part involves using the model as a reference to display the virtual object and the other is the process of updating the model to realize motion or transformation of the object.

5.1 Model Calculation for Displaying

Surface Display gives the position of the user's finger as output and requires an equation of the surface to be given as input. In the reference model calculation for tactile display, the object which is nearest to the finger is selected and the equation of the tangent surface on it is calculated. Therefore, the model must be such that its tangent surface is easily calculated when the finger position is given. As an example of this model calculation process, a curved surface was displayed, and the position and force applyed by the user's finger in tracing the surface was recorded (Fig.-9).

5.2 Model Calculation for Motion and Transformation

Motion or transformation of a virtual object is realized by updating the model. The relation between force and displacement is usually defined by a differential equation. In Surface
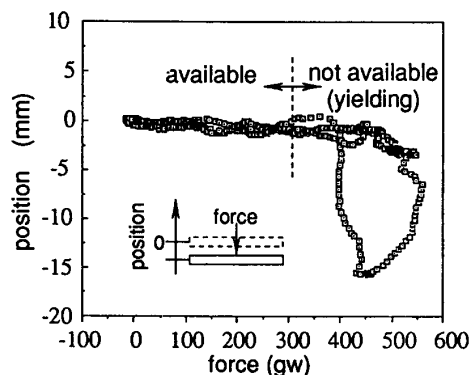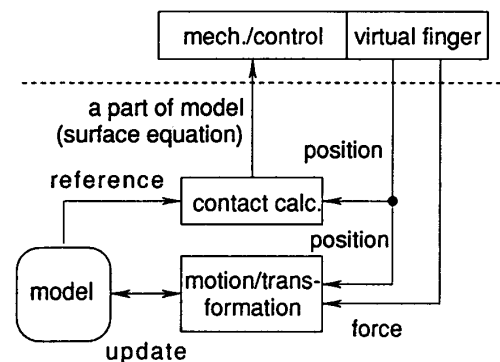

Fig.-7 Measurement of Maximum Force

Fig.-8 Model Calculation

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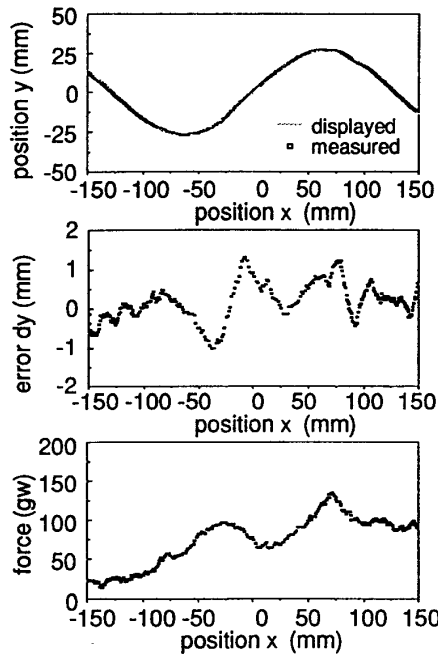(a) Model for Elastic Object

(b) Linear Elasticity

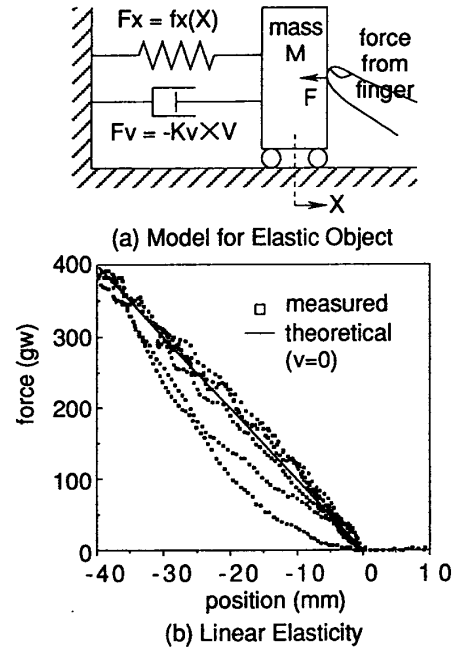Fig.-9 Presentation of Curved Surface

Fig.-10 Presentation of Elastic Object

Display, such an equation is solved as a problem of direct dynamics, namely displacement is calculated when the force is given. The most simple example of transformation is that of an elastic object. In Fig.-10 the physical model of a one dimensional elastic object, which consists of a spring, a mass, and a damper, is solved and elasticity is displayed.

5.3 Time Delay in Model Calculation

The maximum acceptable delay time caused by servo and model calculation in the task of tracing cylindrical surface was estimated, and it was shown to be 2 or 3 milliseconds for servo calculation and about 10 milliseconds for model calculation (Fig.-11(a)). It was also made clear that delays in the servo loop cause instability in control, but on the other hand, delays in model calculation cause not instability, but simply distortion in the tactile displayed object (Fig.-11(b)). In consideration of these facts, calculation of the servo was elected to be carried

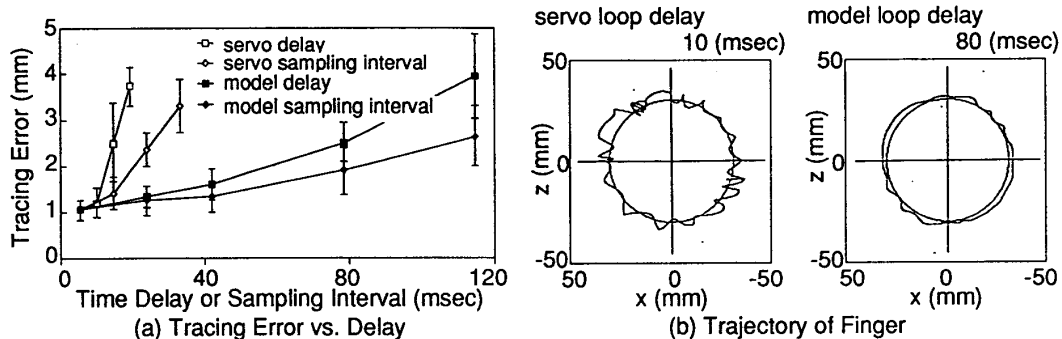(a) Tracing Error vs. Delay

(b) Trajectory of Finger

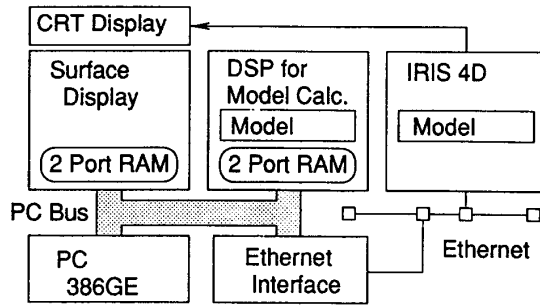Fig.-11 Time Delay Effect in Servo and Model Calculation

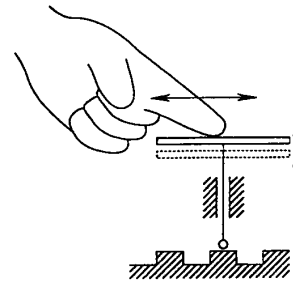Fig.-12 System Structure of Surface Display

Fig.-13 Idea of Pseudo-Texture

out at a frequency of 1 kHz, and the processor for the model calculation was connected with the controller of the Surface Display by PC bus to decrease communication delay (Fig.-12). A graphics workstation to offer visual information was connected by ethernet.

6 Texture

In order to increase the approximation of reality of the displayed object, greater detail of the surface, such as surface texture, should be simulated. As the contact surface of the mechanism itself is flat, such information must therefore be transmitted as oscillations of the contact surface on the vertical axis in accordance with the motion of the user's finger relative to the virtual object. This is called pseudo-texture (Fig.-13). The oscillation is generated by the distance degree of freedom, which regulates distance between the finger and the object. The responsiveness of the mechanism was estimated, and it was shown that the maximum frequency of oscillation having an amplitude of 1 mm was 30 Hz (Fig.-14).

Pseudo-texture is mapped onto the surface of the virtual object in the following manner (Fig.-15). The texture is defined by the texture function, a 2D function relating displacement values to positions in the texture coordinate system. The point in the texture coordinate system (2D) which corresponds to the finger position in the modeling coordinate system (3D) is calculated by using the texture matrix, and displacement of texture at that point is determined from the texture function. This process is called texture mapping.

According to an examination of a user's ability to recognize pseudo-texture, it appears that this method is suitable for displaying coarseness, in terms of height and width of the texture, and orientation of the grain of the texture on the surface (Fig.-16).
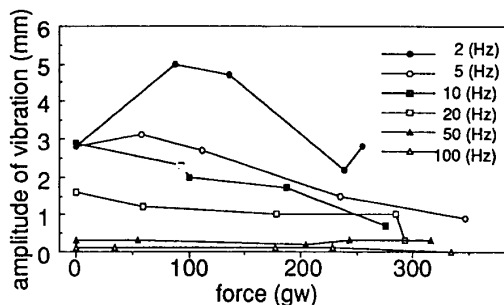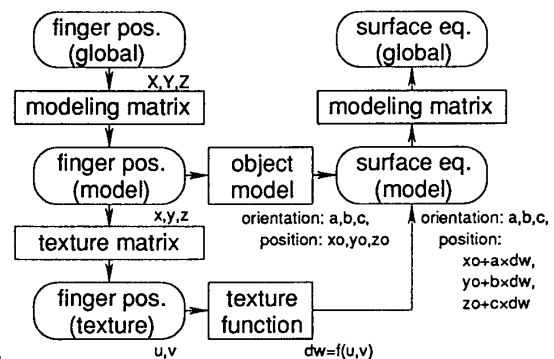

Fig.-14 Responsiveness of Mechanism

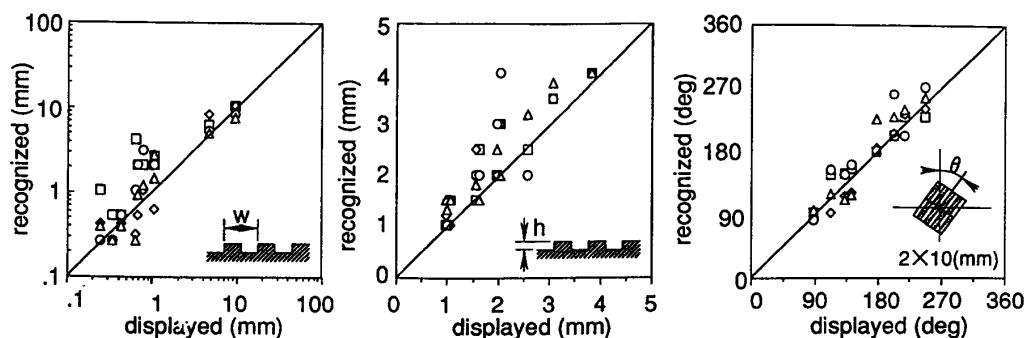Fig.-15 Method of Texture Mapping

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Fig.-16 Recognition of Pseudo-Texture

7 Conclusion

As a methodology to develop a force feedback system, the concept of 'surface displaying' was introduced. A prototype mechanism and its control system was then designed and developed. Methodology for model calculation and simulation was discussed. Finally, the idea of texture mapping in a tactile sense was suggested, and was proven to be effective.

Acknowledgments

References

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